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Thermal Power Installation for a Water Engine

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Abstract—We present the main principles for developing a water-jet thermal power installation that uses a propeller operating on jet thrust developed during the flashing of metastable water. The considerable advantages of using the proposed thermal power installation as a water jet propeller over existing marine engines constructed on the basis of screw propellers are shown.

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A thermal power installation for a water jet engine (WJE) or a water-jet propeller has some advantages over a similar installation equipped with a screw propeller, although it is inferior to the latter in pulling force (approximately by 15–20%). Experimental studies the results of which are presented in [1] have shown that not only can the above-mentioned losses be compensated for, but the thrust can be increased by several times. Two problems must be solved for achieving this. First, a device for heating the ejected water to the required temperature should be installed in the line between the power installation and the nozzle. Second, it is necessary to develop an optimal design of the nozzle through which water discharges. In doing so, it should be borne in mind that thrust increases only during outflow of water that is in metastable state and not in the form of steam or steam–water mixture, because the thrust drops very much in the latter case. Water is heated to temperature that must not exceed the saturation temperature.

Investigations of jet power resulting from outflow of metastable liquid [2, 3] have shown that the jet reaction decreases as water discharging from a hole or a convergent nozzle is heated to higher temperature.

The relative jet force is given by $R_{\text{rel}} = R_{\text{ex}}/R_{\text{c}}$, where R_{ex} is the experimentally measured jet force in case of liquid discharging from convergent nozzles and R_{c} is the jet force resulting from discharging of nonflashing cold ($t < 100°\text{C}$) water into the atmosphere. The relative temperature is given by $\theta_s = T_0/T_{0s}$, where the subscript “0” corresponds to initial values and the subscript s corresponds to the parameters on the saturation line. The experiments were carried out with the pressures of water at the channel inlet equal to 3.0, 5.0, 7.0, 12.5, 14.0, and 15.0 MPa. The main conclusion drawn from the obtained results is that the jet reaction drops by approximately a factor of 2 as the temperature approaches the saturation temperature. A drop in the jet reaction is a favorable phenomenon when emergency situations occur in nuclear power installations; however, it cannot be considered as a positive effect if we wish to develop a water jet propulsion engine. On the other hand, experiments carried out with a divergent nozzle (Laval’s nozzle) have led to the opposite effect [4]. Figure 2 shows the relative jet power as a function of relative temperature for nozzles (and other channels) with a divergent profile at the outlet under discharging conditions with heterogeneous nucleation.

Figure 3 shows an extrapolation of the averaged experimental data to a pressure of 18 MPa (with the nozzle diameter $d_{\text{n}} \approx 1$ mm). The relative force is given by $R_{\text{rel}} = R/R_{\text{c.w}}$, where R is the maximal jet force developed during outflow of metastable liquid and $R_{\text{c.w}}$ is the maximal jet force developed during outflow of cold nonflashing liquid.

The dependence presented in Fig. 3 is described by the following equation:

$$R_{\text{rel}} = 5.6798\varepsilon_{\text{cr}}^2 - 3.3243\varepsilon_{\text{cr}} + 2.486,$$

where $\varepsilon_{\text{cr}} = p/p_{\text{cr}}$ and $p_{\text{cr}} = 22.5$ MPa.

With metastable liquid discharging through a channel having a divergent outlet, an increase in the temperature causes the jet reaction to increase by more than a factor of 2, an effect due to which a divergent nozzle can be used as a propelling device for a water-jet engine.

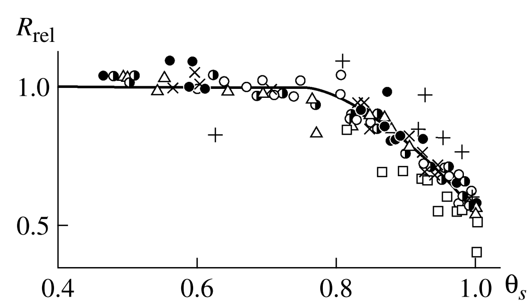

Fig. 1. Relative thrust force vs. the relative initial temperature of water. Points are for experimental data, and the curve is a generalization of experimental data.

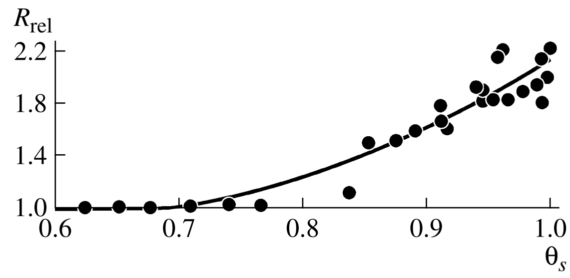

Fig. 2. Relative jet reaction vs. the relative temperature for discharge from nozzles with a divergent outlet part. The notation is the same as in Fig. 1.

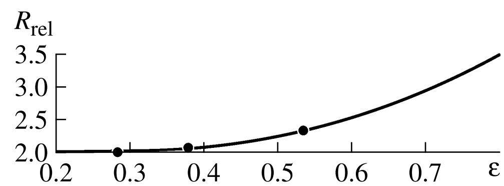

Fig. 3. Extrapolation of experimental data for high pressures.

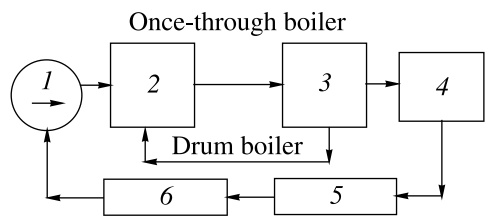

Fig. 4. Schematic diagram of a steam-powered ship engine. (*1*) Pump, (*2*) economizer part of the boiler, (*3*) evaporating and steam-superheating part of the boiler, (*4*) turbine unit, (*5*) condenser, and (*6*) water-treatment system.

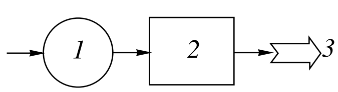

Fig. 5. Schematic diagram of a jet propulsion engine for a ship. (*1*) Pump, (*2*) economizer part of the boiler, and (*3*) nozzle.

A water-jet engine is much simpler than any steam engine. Its effectiveness and economic efficiency must be considered individually for each specific layout. The nozzle, constructed as a Laval nozzle, has a divergent part at the outlet (we will conventionally call it a diffuser) and is calculated for concrete initial and boundary conditions taking the metastable state of flow into account. The thrust force increases severalfold in this case. During engine operation, a device for heating water can be switched on whenever necessary (for boosting) or may operate continuously. Such a version of the engine can be installed on both marine and submarine ships, because a pump will in any case develop a pressure difference across the outlet nozzle. The design advantages of the proposed water-jet propulsion engine are graphically shown in Figures 4 and 5.

Three kinds of pumps can be used.

(i) It may be a *mechanical* pump equipped with an appropriate power drive.

(ii) It may be a *thermal* pump that heats water in a separate vessel to the required pressure and then supplies it to the main boiler, which collects water with the design pressure from a few individual vessels. Water in the main boiler is heated to the required temperature and is fed to a nozzle, or water from a few individual vessels is brought to the required pressure and temperature and fed, turn by turn, to the nozzle. In this case, the water-jet engine operates as a pulsating propeller.

(iii) It may be a *chemical* pump powered by the heat releasing as a result of a chemical reaction.

A water-jet engine can be used in different versions: as the main engine instead of a screw-propeller one, as a device supplementary to a screw-propeller one as a booster connected for a periodic interval of time, and as a maneuvering engine connected when a need arises to make a complex and rapid maneuver. It can be used merely as a booster for various floating devices or for special constructions. An individual optimal version of power installation must be developed for each concrete application. Individual principles and designs of a heating element, a pump, and a nozzle (a system of nozzles) must be used for each individual version.

CONCLUSIONS

(1) Application of water-jet propulsion engines makes it possible to avoid the need of using the processes of boiling water, obtaining steam and superheating it, converting the energy of steam into mechanical energy of rotating a shaft through a turbine, and developing thrust by rotating a propeller on the shaft.

(2) Application of water-jet propulsion engines makes it possible to exclude all stages of converting the energy of fuel into energy of motion with the exception of heating water to the saturation temperature at the required pressure and obtain a gain in thrust force. The gain is achieved due to the specific features pertinent to the discharge of metastable liquid through channels with a divergent outlet, i.e., the mode in which metastable liquid heterogeneously flashes in the divergent part of a channel.

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